Estimating Deposition to Lake Tahoe

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LTADS Primary Objective

- Characterize dry deposition to Lake
  - Pollutants affecting Lake clarity
  - Phosphorus, Nitrogen, Particles

Overview of Topics

- Process of Atmospheric Deposition
- What Controls Deposition Rates?
- Concentrations for Deposition Estimates
- Deposition Velocity Calculations
- Deposition Rate Estimates
- Uncertainties

Deposition to Lake Tahoe

- Transfer of mass from atmosphere to water
- Wet or dry processes
- Precipitation removes soluble species:
  - NO_3^-, NH_4^+, organic N
- Dry processes (uptake, diffusion, interception, impaction or sedimentation) remove gaseous species and particles:
  - gaseous HNO_3, NO_2, organic species, NH_3
  - particulate NH_4^+ and NO_3^-, Phosphorus, PM mass

What Sets Dry Deposition Rates?

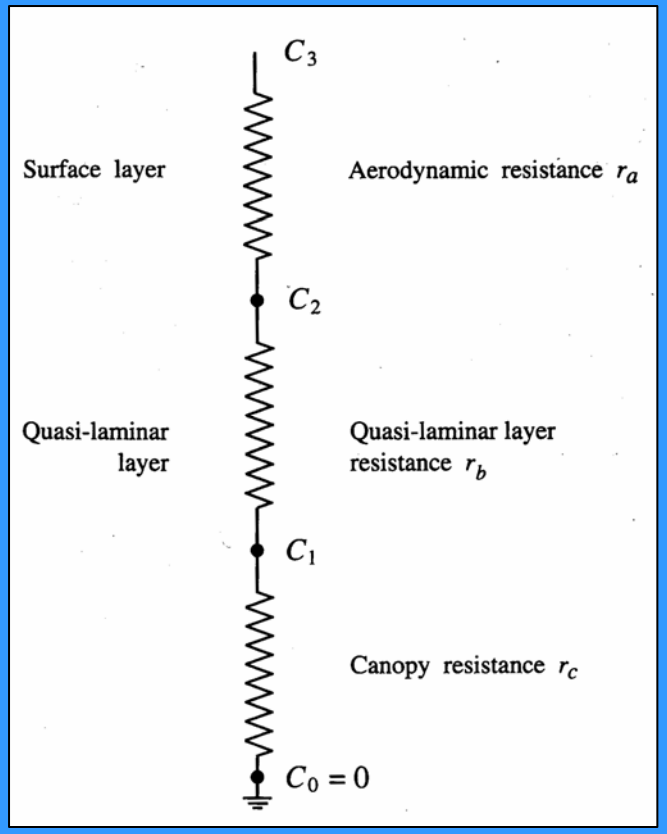
- Concentration
- Largest Particles:
  - Settling velocity (PM size, density)
- Gases and Smaller Particles:
  - Multiple Rate Limiting Steps
- Deposition Velocity
  - Deposition Rate/Concentration
  - Normalized Rate - Not a Process
  - Differentiate from Settling Velocity

Dry Deposition of Gases and PM

1. Turbulence mixes pollutants toward "sink"
   - Atmospheric turbulence set by wind speed, surface roughness (decreased by thermal stratification)
   - Aerodynamic Resistance
2. Diffusion across very thin laminar layer
   - Depth of layer (wind speed. surface elements)
   - Rate of diffusion (particle size, molecular weight)
   - Quasi-laminar Resistance ~ 0
3. Capture by surface
   - Pollutant solubility, chemical reactivity
   - Surface type, biophysical factors (stomatal opening)
   - Surface Resistance ~ 0 for species of interest

Three-Step Deposition Model

- Resistance Analogy
  - Aerodynamic Resistance
  - Laminar Layer Resistance
  - Surface Resistance



Rate of Deposition of Gases to Water

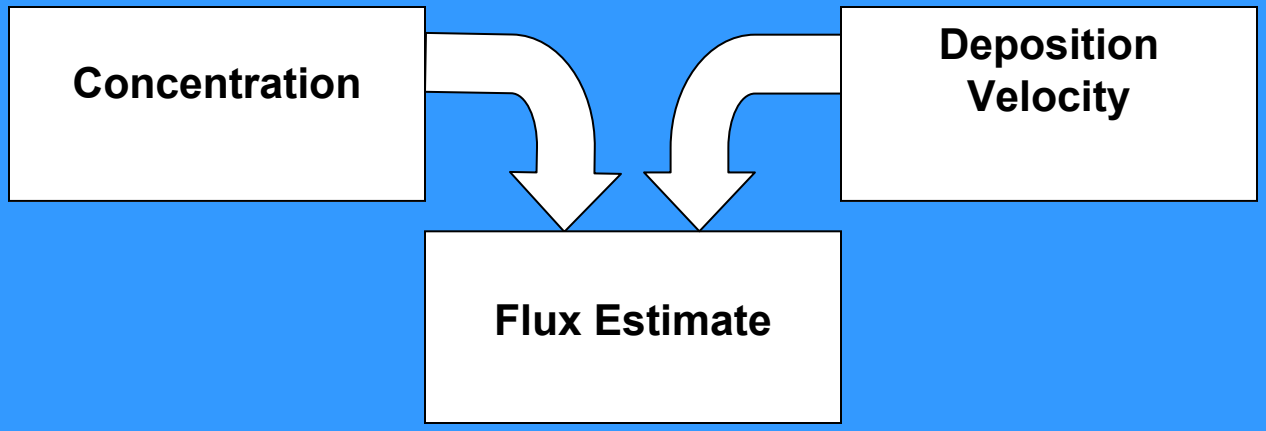
- Highly Reactive or Soluble?
  - Surface Resistance ~ 0
  - Aerodynamic Resistance Sets Rate
  - What determines turbulence?
    - Wind speed
    - Upwind roughness (fetch)
    - Thermal Stratification
- Relatively Insoluble Gas?
  - Surface Resistance Sets Rate

PM Deposition to Water

- Surface Resistance ~ 0 for Particles
- Quasi-Laminar, Aerodynamic Resistances
  - Wind Speed
  - Particle Size
- Potential for Water to Modify Processes and Resistances
  - Hygroscopic particle growth
  - White caps and spray

Calculation of Deposition

- Deposition Flux (F) = C x V_d



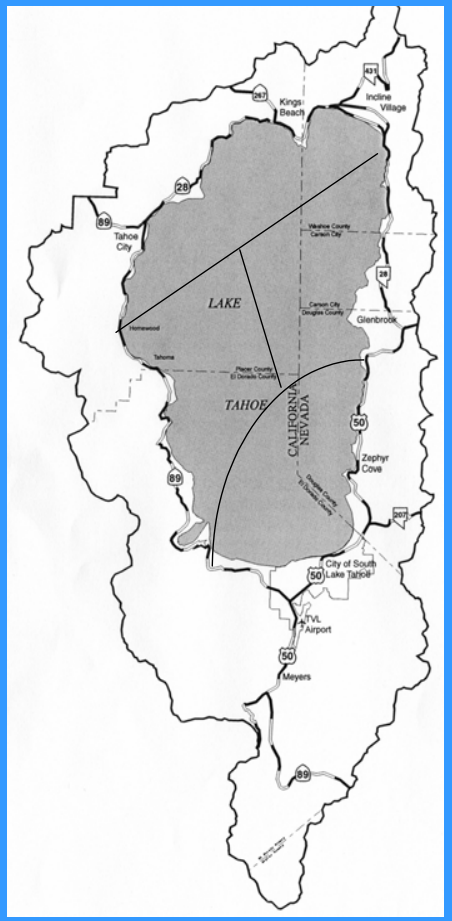
- Hourly Velocities & Concentrations
- Hourly Deposition Rates
- Summed over year

LTADS Concentrations Used in Deposition Estimates

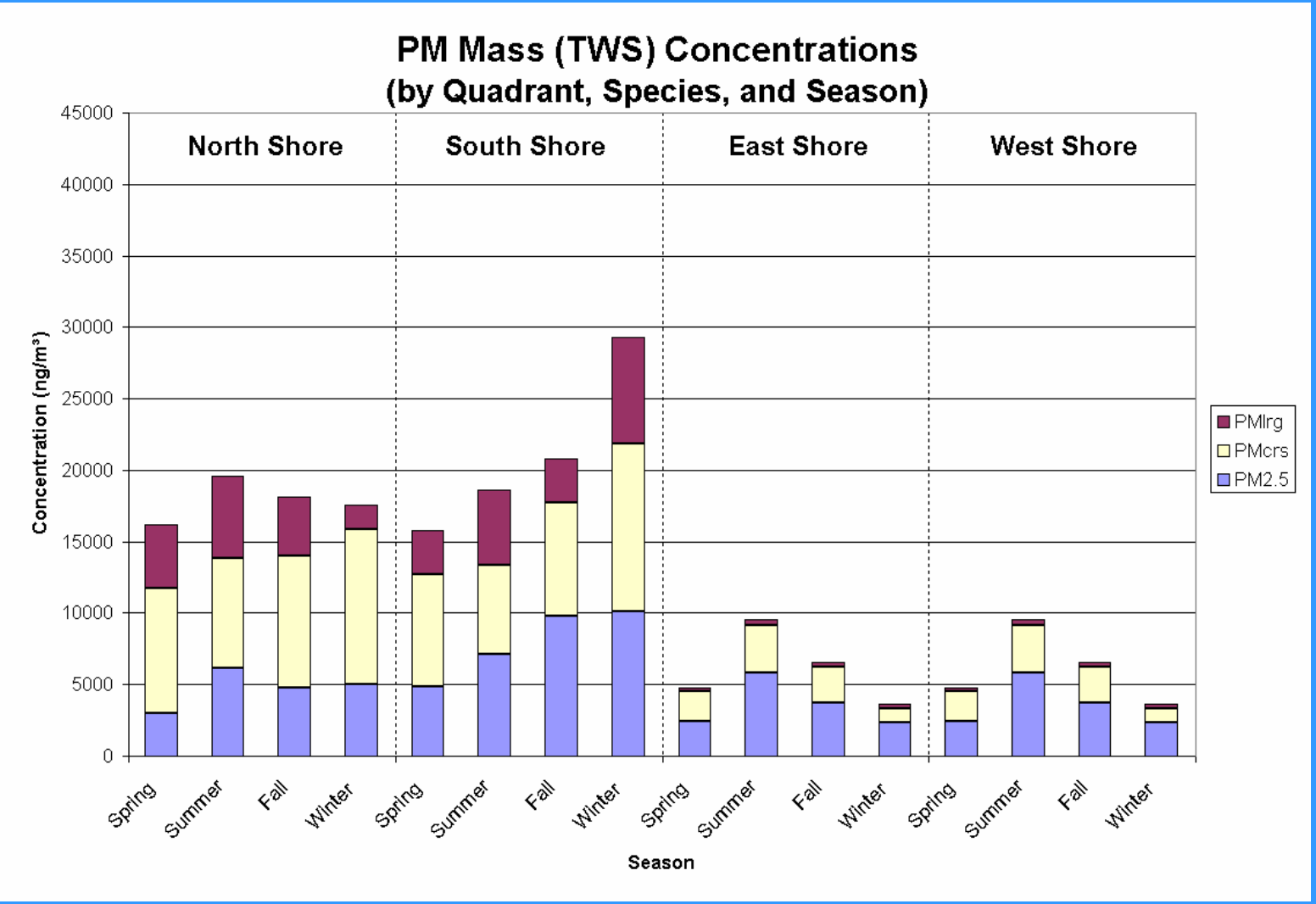
- Two-Week Concentrations (TWS)
  - Nitric Acid, Ammonia
  - PM mass, chemistry: PM2.5, PM10, TSP
- Hourly PM mass (BAMs)
  - PM2.5, PM10, TSP
  - 24 hour mass
  - Seasonal average of hourly mass

Gross Spatial Variation of Concentrations

- Zones selected for similarity
- Population densities
- Emissions activity levels
- Upwind sources
- Represented by measured concentrations (TWS)
- Modulated hourly by season by mass observations from BAMs

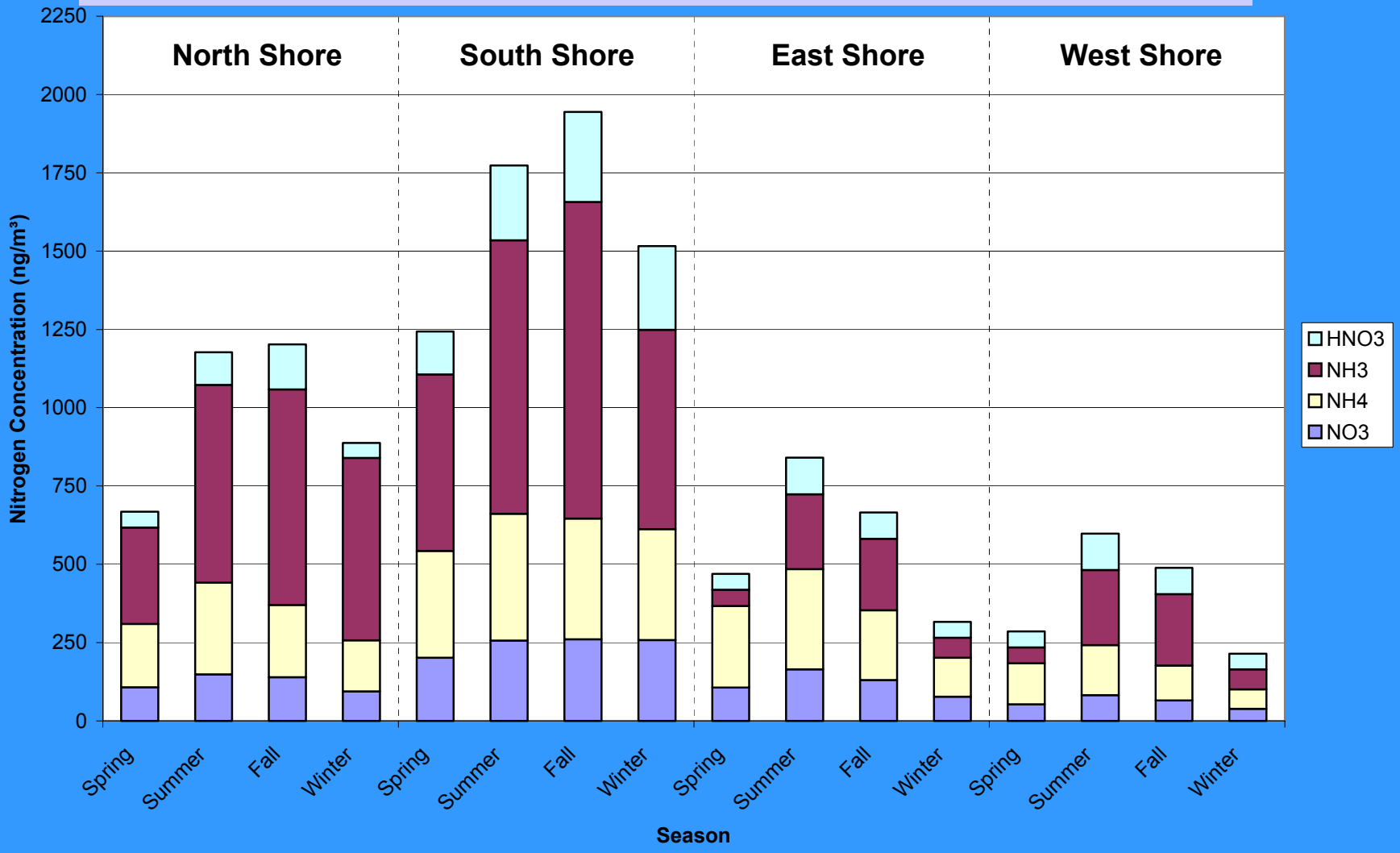


Seasonal PM Concentrations

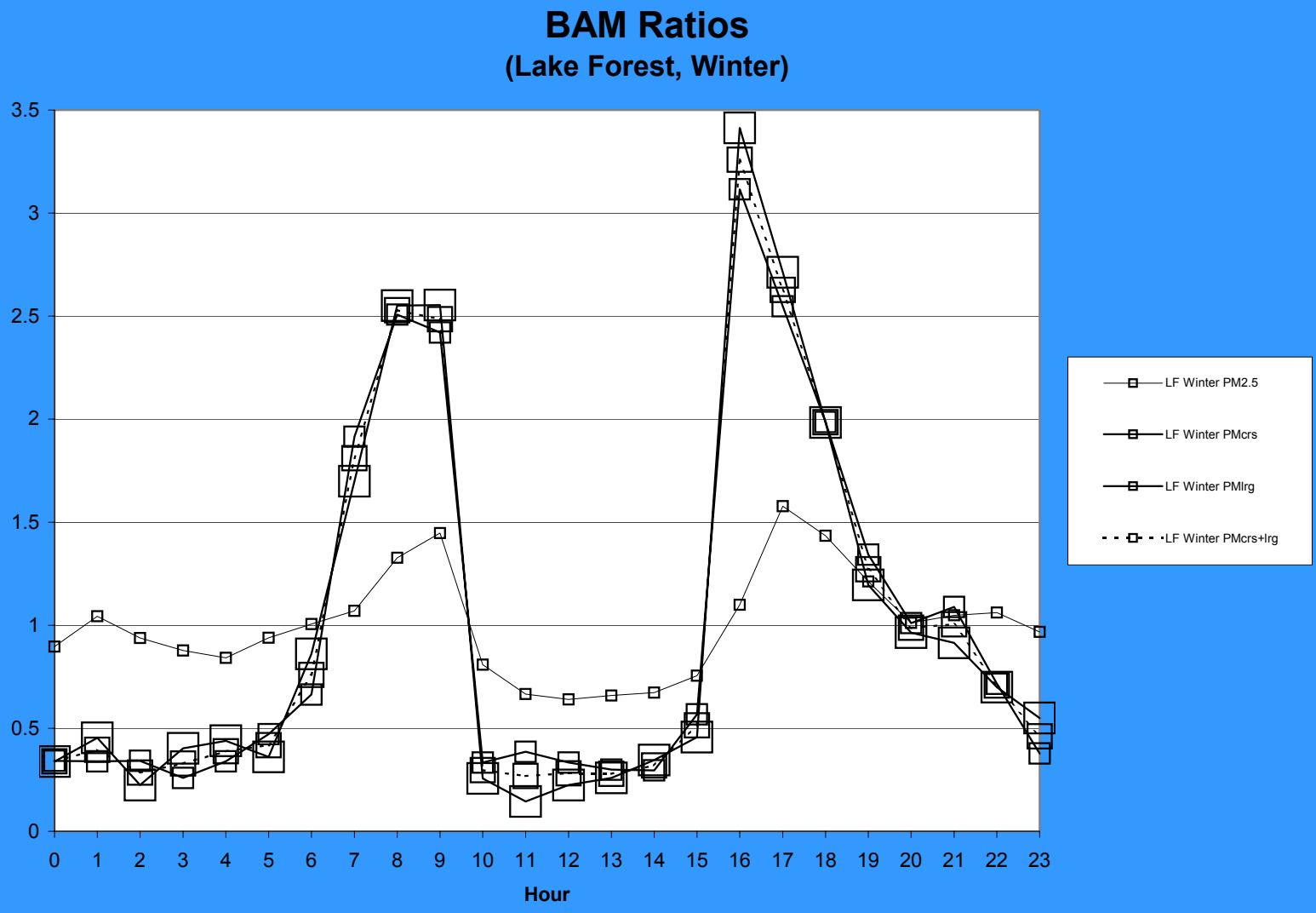


Seasonal N Concentrations

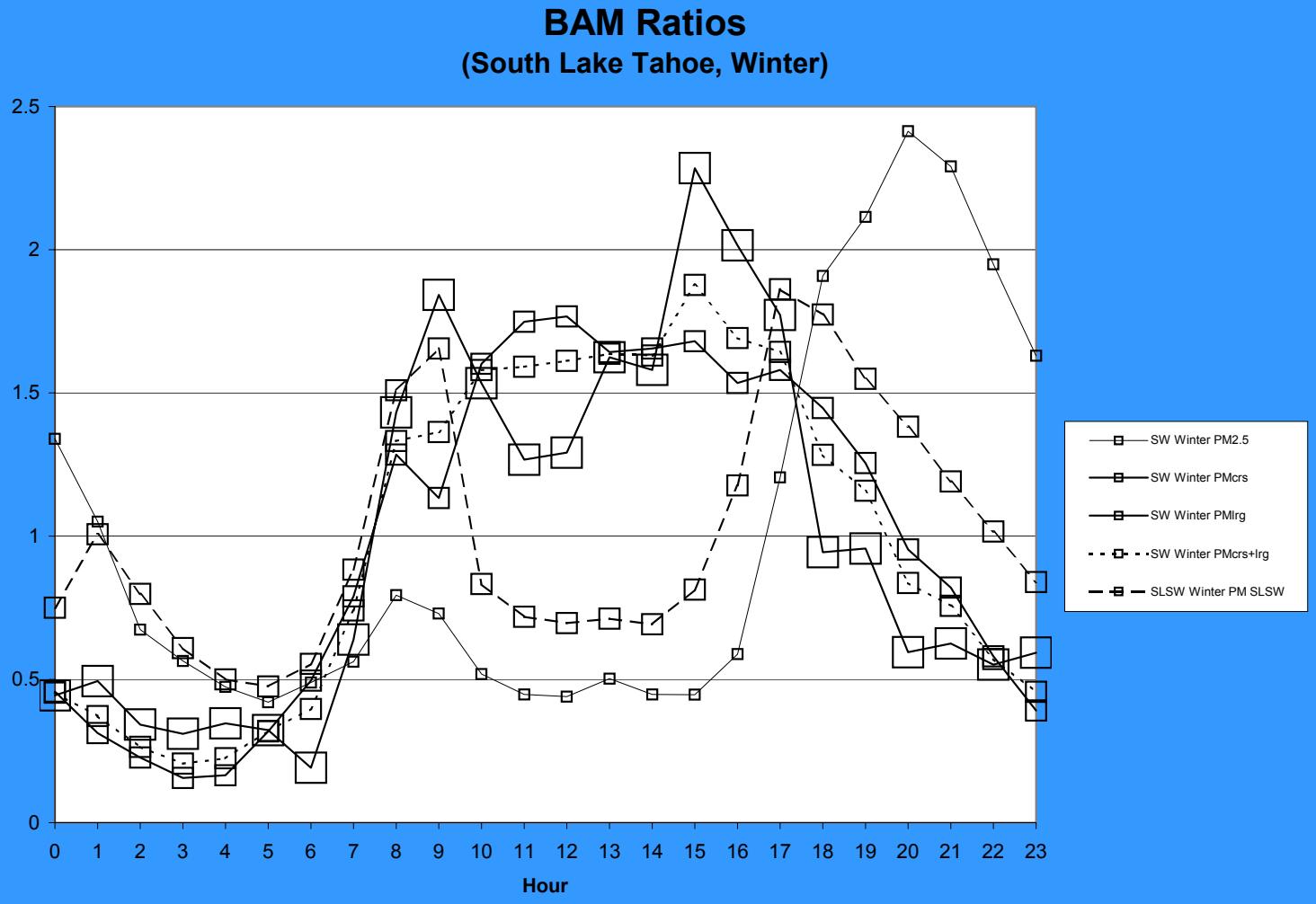
Nitrogen Concentrations (by Quadrant, Species, and Season)



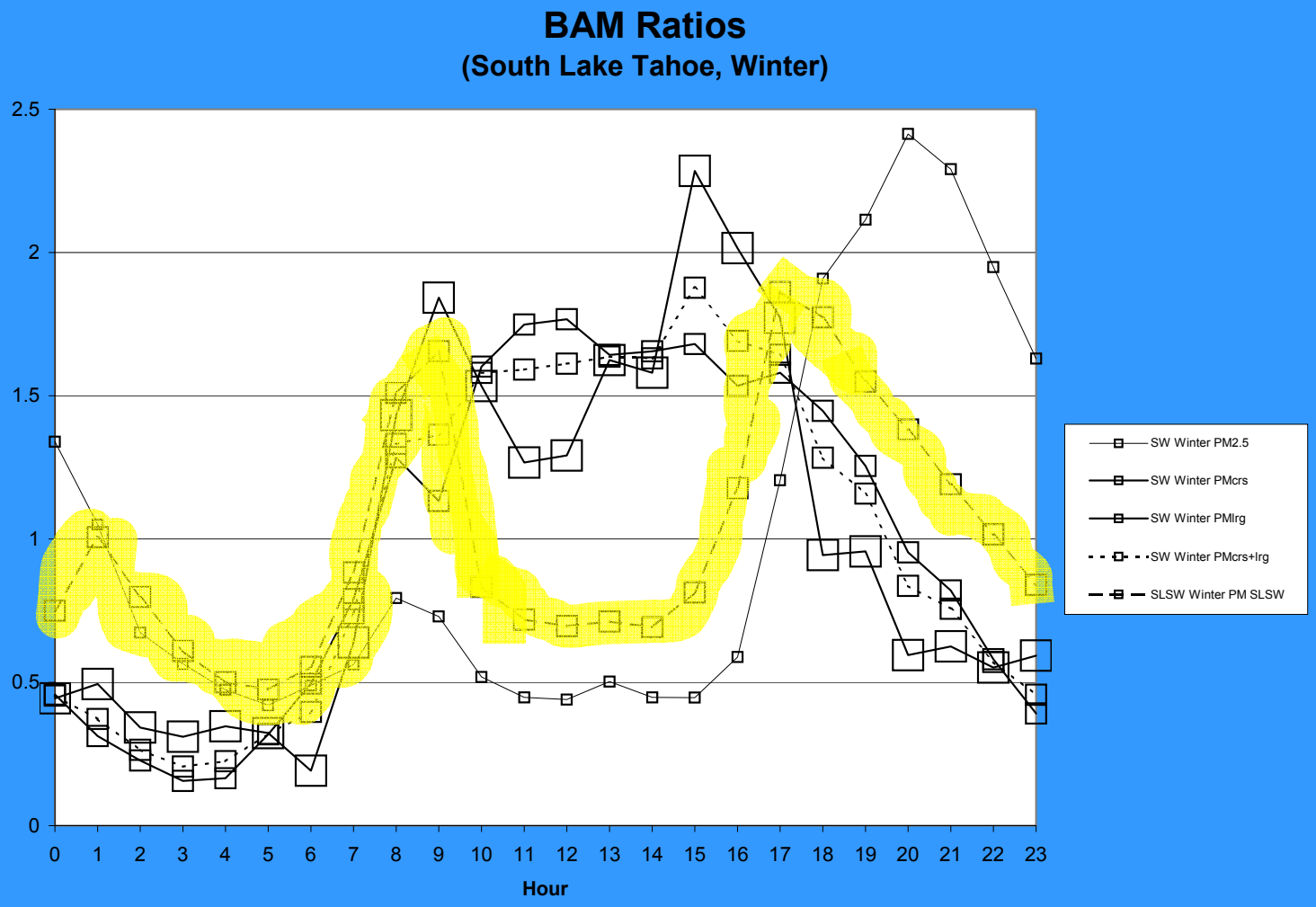
Winter BAM PM Observations at Lake Forest



Winter BAM PM Observations at SLT



Winter BAM PM Observations at SLT



Meteorological Measurements

- Wind speed, direction
- Temperature and humidity
- Surface & aloft observations
- For deposition velocity - hourly observations over Lake
  - Winds, air and water temperature

Wind Speed Frequency

Wind (m/s)	U.S. Coast Guard Pier				
	Annual	Spring	Summer	Fall	Winter
0 - 0.5	0.03	0.02	0.02	0.02	0.06
0.5 - 1.5	0.19	0.18	0.20	0.17	0.20
1.5 - 3	0.48	0.42	0.51	0.50	0.50
3 - 5	0.16	0.18	0.15	0.18	0.14
5 - 7	0.09	0.14	0.09	0.08	0.07
7 - 10	0.04	0.05	0.03	0.05	0.03
10 - 12	0.00	0.01	0.00	0.01	0.00
12 - 999	0.00	0.00	0.00	0.00	0.00
N =	8356	2206	1882	2126	2142

Wind (m/s)	TDR1 Buoy				
	Annual	Spring	Summer	Fall	December
0 - 0.5	0.03	0.02	0.02	0.02	0.11
0.5 - 1.5	0.20	0.18	0.17	0.17	0.33
1.5 - 3	0.51	0.42	0.44	0.50	0.81
3 - 5	0.17	0.18	0.12	0.18	0.23
5 - 7	0.10	0.14	0.08	0.08	0.11
7 - 10	0.04	0.05	0.03	0.05	0.04
10 - 12	0.00	0.01	0.00	0.01	0.00
12 - 999	0.00	0.00	0.00	0.00	0.00
N =	8354	2205	1882	2125	2142

Surface Winds

- Local mesoscale winds dominate
- Generally weak (< 3 m/s) winds ~ 70 % of hours
- Weaker at SS ~ 94 % < 3 m/s
- Dominant wind direction is offshore at most sites
  ~ 50 – 75 % of hours
- Onshore is secondary direction
  ~ 20 – 30 % of hours
- Sideshore infrequent
  ~ 10 - 15 % of hours

Hourly deposition velocities of gases

- $V_d = F / (C - C_0) \Rightarrow F = V_d * C$
- $V_d = 1/(R_a + R_b + R_c) \Rightarrow V_d = 1/(R_a)$
- $R_a = U / (U^*)^2$
  - Hourly values calculated from local wind obs
  - Two calculation methods used
  - Similarity theory not applicable near shoreline
  - Near shore define $1/R_a$ = 6 cm/s, advection of TKE
  - May exaggerate deposition
- Near-shoreline concentrations applied to Lake

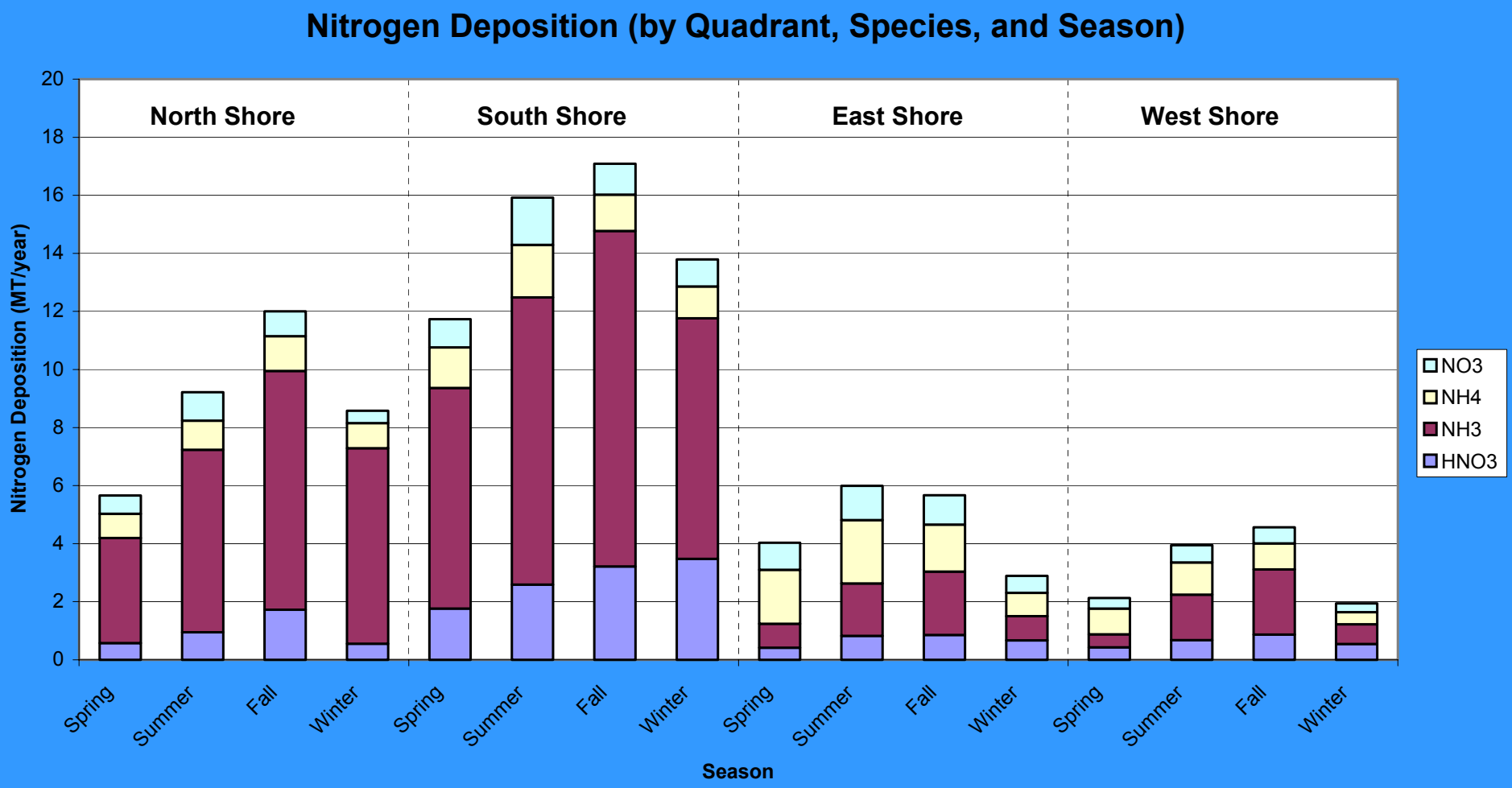
Conservative Assumptions

- No decrease of concentration offshore
- Dry deposition occurs 24 – 7 - 365
- Characteristic PM Diameters

	PM2.5	PMcrs	PMlrg
– Lower	1	5	10
– Best	2	8	20
– Upper	2.5	10	25

- turbulence & deposition near shore are exaggerated during offshore flow
  (1/Ra for lower, best, upper as 3, 6, 10 cm/s)

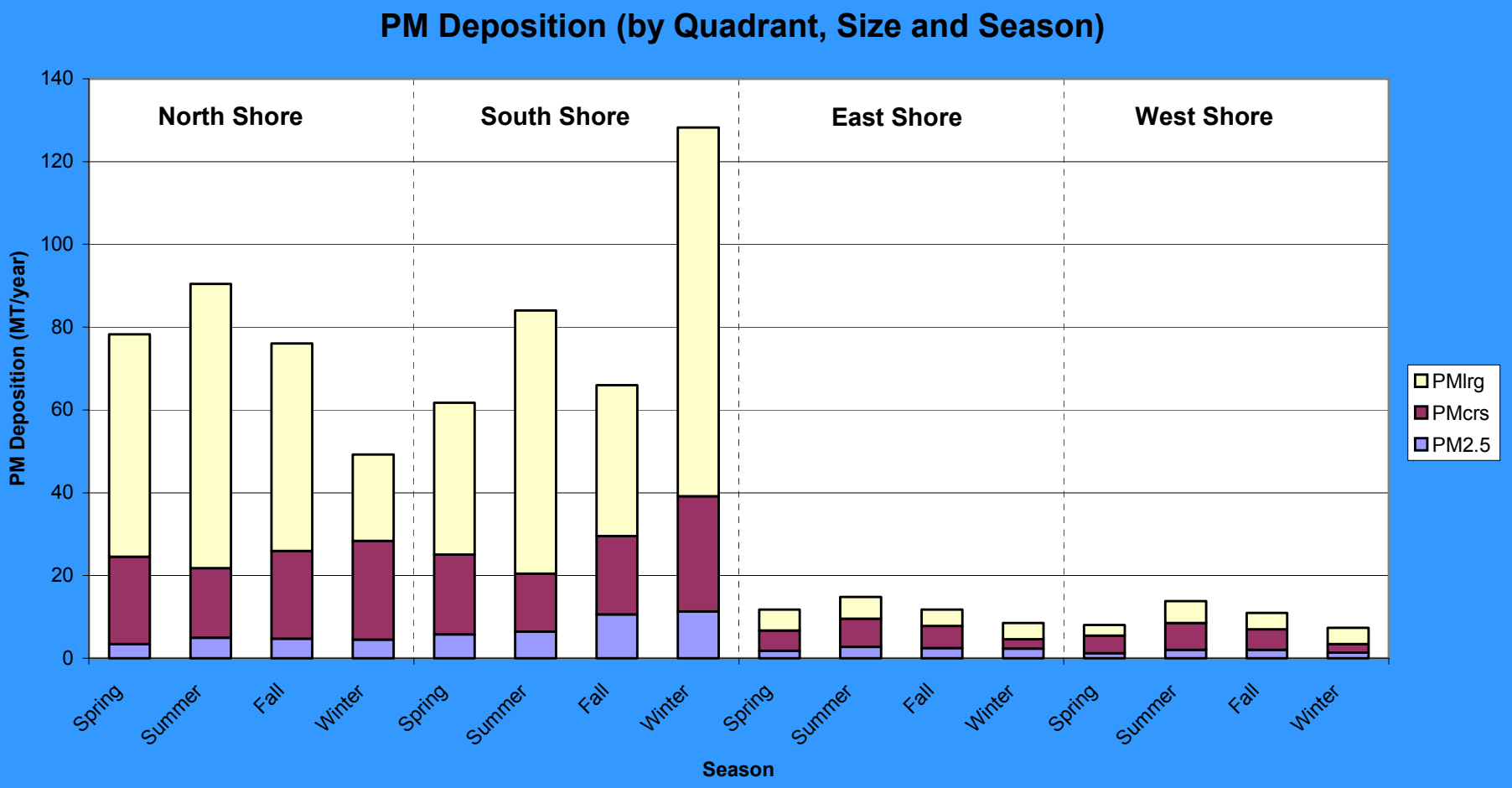
Dry Deposition of Nitrogen (~120 MT/Year) by zone, season, chemical species



Deposition of PM

- Venkatram and Pleim (1999)
- $V_d = V_g/[1- e^{-Vg(Ra +Rd +Rc)}]$
- $R_a = U / (U^*)^2$ estimated by two methods
- Near shore with offshore wind
  - $1/R_a$ defined as 6 cm/s
  - exaggerates advection of TKE in first km

Dry Deposition of PM Mass
(~700 MT/Y) by size, zone, and season



Deposition (MT/year) Original Draft Estimate (assumed P 10, 20, 30 ng/m3)

Pollutant	Lower Estimate	Best Estimate	Upper Estimate
N (NH_3, NH_4^+, HNO_3, NO_3^-)	70	100	150
P (P, PO_4^{-3})	0	1	3
PM (in 3 size ranges)	440	720	1060

Assumed P Concentration Revised Upward

- Estimate of P concentrations may be low due to laboratory analytical factors specific to P detection and P detection with Si.
- P LOD revised upward ~60 ng/m3 (Cahill)
- Average P concentration is ~40 ng/m3
  - Averaged all P measurements (with non-detects treated as ½ LOD, i.e., 20 ng/m3)
- P dry deposition estimate approximately doubled ~ 2.5 MT/year

Deposition (MT/year)
(40 ng P/m3 as Lake average)

Pollutant	Lower Estimate	Best Estimate	Upper Estimate
N (NH_3, NH_4^+, HNO_3, NO_3^-)	75	110	170
P (P, PO_4^{-3})	0.7	2.5	3.6
PM (in 3 size ranges)	440	720	1060

Revision, P & PM concentrations decrease offshore

- Comment: Shore concentration is overly conservative for PM at mid Lake
- Thunderbird assumed as lower Lake limit
- TB, Bliss unchanged
- Deposition in N & S zones was scaled downward based on PM differences by size fraction, LW-TB, SW-TB.
- Scaled downward by 25 % of difference

Dry Deposition of PM Mass & Phosphorus (MT/Yr)

(With Scaling of TB-SW, TB-LF Differences)

	Base Estimate	Scaled – 25%
• Mass PM2.5	70	60
• Mass PMcrs	200	170
• Mass PMlrg	450	360
• Mass TSP	720	590

Scaling the previous phosphorus deposition estimate of 2.5 MT/year in the same manner predicts 1.2 MT/year.

Dry Deposition of PM Mass & Phosphorus (MT/Yr)

(With Scaling of TB-SW, TB-LF Differences)

	Base Estimate	Scaled – 25%
• Mass PM2.5	70	60
• Mass PMcrs	200	170
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• Mass TSP	720	590

P deposition based on PM deposition and P content per Emission Inventory

• P – PM2.5	0.05	0.04
• P - PMcrs	0.34	0.29
• P – PMlrg	0.86	0.68
• P – TSP	1.3	1.0

EI % P => PM2.5 = 0.07, PMcoarse = 0.17, PMlarge = 0.19% P